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RESISTANCE TRANSFER TECHNIQUE

by

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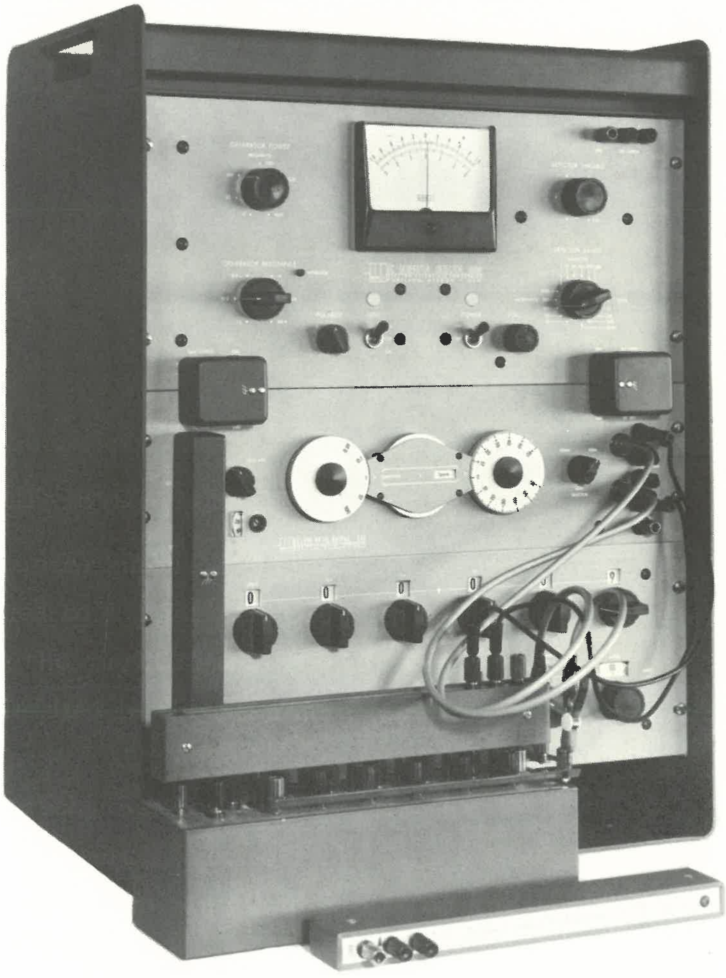

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National Conference of Standards Laboratories

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June 25, 1963

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RESISTANCE TRANSFER TECHNIQUE

A resistance transfer technique is explained and the script and pictures of an audio-visual program for making two specific resistance transfers is given.

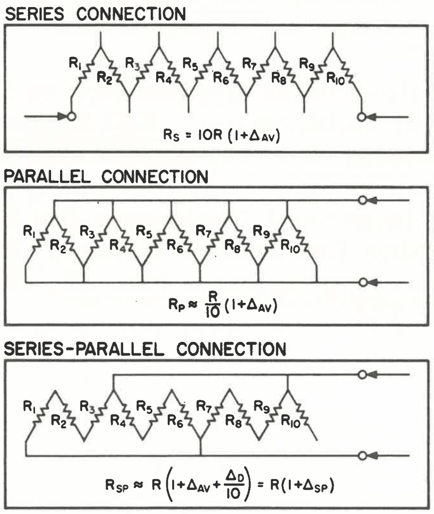
The transfer technique uses a set of four-terminal resistors permanently connected in series to make accurate resistance comparisons between resistors of different values.

The audio-visual system is programed to use specific measuring equipment for the calibration of two particular resistance values relative to a given standard of another value. Although recorded voice instructions and colored illustrations provide the greatest training value, these written instructions and black and white pictures serve to illustrate the technique. The program can be changed to use different measuring equipment and resistance values.

THE TECHNIQUE

Transfer of resistance by steps of ten is often done when calibrating or comparing resistance standards.

Ten resistors permanently connected in series can be reconnected in series-parallel for a ten-to-one value change. The same ten resistors can be connected in parallel for a one hundred-to-one value change. These connections and the resulting accuracy equations are shown in Figure 1.


SERIES CONNECTION
R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10}
$R_S = 10R(1+\Delta_{AV})$
PARALLEL CONNECTION
R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10}
$R_P \approx \frac{R}{10}(1+\Delta_{AV})$
SERIES-PARALLEL CONNECTION
R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10}
$R_{SP} \approx R\left(1+\Delta_{AV}+\frac{\Delta_D}{10}\right) = R(1+\Delta_{SP})$

Where R_i = nominal resistance of the ith resistor
Δ_i = deviation of R_i from R $\quad R_i = R(1+\Delta_i)$
R_S = resistance of 10 resistors in series
R_P = resistance of 10 resistors in parallel
R_{SP} = resistance of 9 resistors in series-parallel
Δ_{AV} = average deviation of the 10 resistors $\quad \Delta_{AV} = \frac{1}{10}\sum_{i=1}^{10}\Delta_i$
Δ_D = deviation of R_{SP} from the tenth resistor R_{10}
Δ_{SP} = deviation of R_{SP} from R $\quad \Delta_{SP} = \left(\Delta_{AV}+\frac{\Delta_D}{10}\right)$

These formulas are correct to about $\pm\left(\frac{1}{10}\sum_{i=1}^{10}\Delta_i^2 - \Delta_{AV}^2\right)$ (±1ppm if the build-up resistors are accurate to ±0.1% and there are no connection errors)

FIGURE 1. BUILD-UP RESISTOR CONFIGURATION

THE EQUIPMENT

The equipment for the technique includes the Model 242 Resistance Measuring System, three Model SR 1010 Resistance Transfer Standards, two compensation networks and a pair of shorting bars. They are shown in Figure 2.

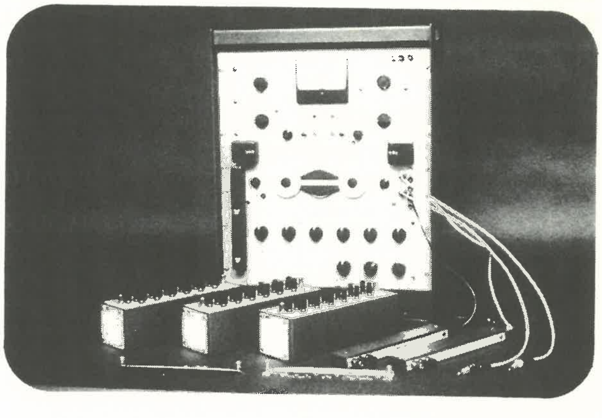


FIGURE 2. TRANSFER EQUIPMENT

The ESI Model 242 Resistance Measuring System is used as a substitution type comparison bridge for extremely accurate one to one resistance comparison measurements. The 242 System provides both resistance measuring dials and a deviation dial. The deviation dial and resistance dials can be used in sequence to eliminate the need for measurement calculations. The four-terminal capability of the Model 242 permits high accuracy low resistance measurements. Adjustable supply voltage and detector sensitivity allow meter calibration to improve resolution for comparison measurements at the ppm level.

The ESI Model SR 1010 Resistance Transfer Standards are sets of nominally equal resistors permanently connected in series. They are available in decade resistance values of one ohm per step to one megohm per step. The resistors are connected by true four-terminal point junctions. Typical junction resistance is less than 0.1 microohm. The precision resistors feature low temperature and power coefficients and excellent short term stability.

The ESI Model SB 103 Shorting Bars are designed to simplify the parallel and series-parallel connections of the resistors in an SR 1010 box. For low value resistance boxes both the SB 103 Shorting Bars and the PC 101 and SPC 102 networks are required for accurate parallel and series-parallel connections.

The ESI Model PC 101 Parallel Compensation Network is a set of nominally equal resistors used to connect ten resistors of a Model SR 1010 in a four-terminal parallel arrangement. The network insures high transfer accuracy for low value parallel resistance measurements.

The ESI Model SPC 102 Series-Parallel Compensation Network is a set of nominally equal resistors used to connect nine resistors of a Model SR 1010 in a four-terminal series-parallel arrangement. The network assures high transfer accuracy for low value series-parallel measurements.

MORE ABOUT RESISTANCE MEASUREMENT

(1) Precision Resistance Measurement-Part I. ESI Design Ideas, Vol. 1, No. 2, July 1960.

(2) Precision Resistance Measurement-Part II. ESI Design Ideas, Vol. 1, No. 3, November 1960.

(3) Traceability of Resistance Measurements. ESI Engineering Bulletin, EB-30, April 1962.

(4) Audio-Visual Application to Equipment Calibration. ESI Engineering Bulletin No. 33, September 1962.

(5) An Improved Technique for Establishing Resistance Ratios. ESI Engineering Bulletin No. 35, November 1962.

DETAILED TRANSFER TECHNIQUE

With a general outline of the transfer technique in mind, let's select a portion of it for closer study. Now we can concentrate on proper use of the equipment for precision transfer measurements.

The following procedure involves the calibration of a 100 ohm and 1 kilohm standard resistor from a 10 ohm standard resistor. It is complete in every detail and can be used as a guide for actual transfer calibration work.

The following equipment is required:

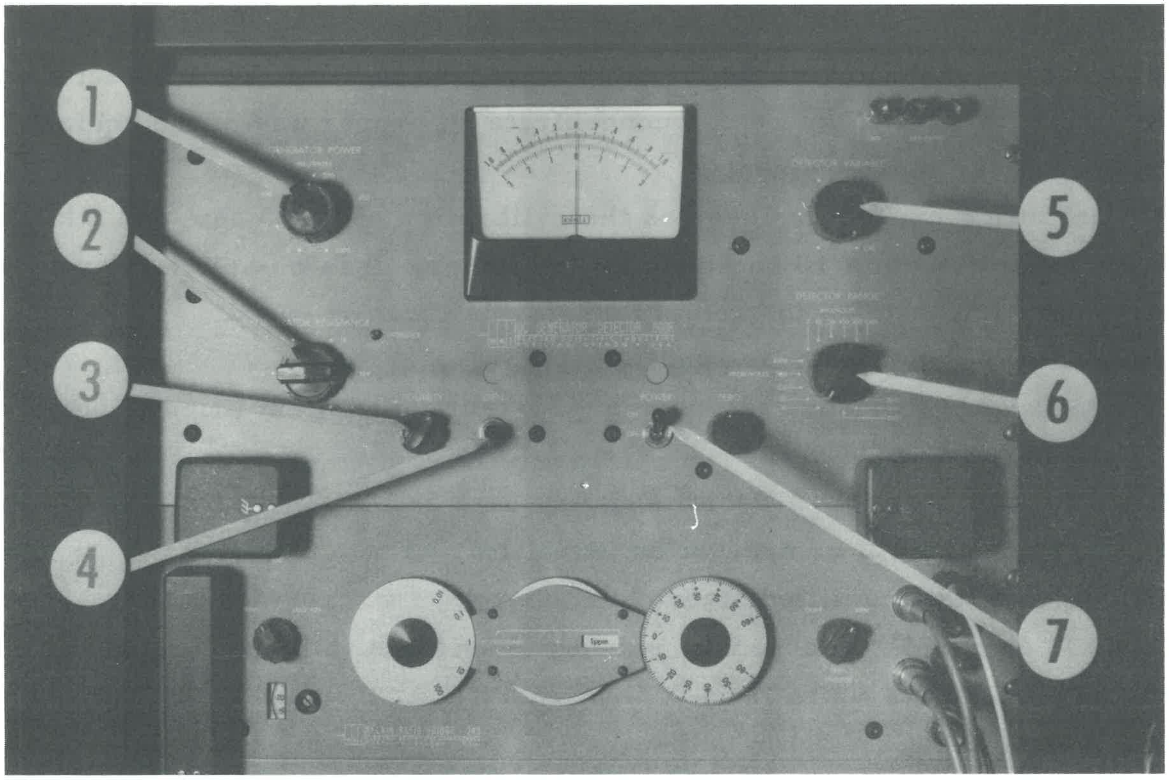
(1) Model 242 Resistance Measuring System with Kelvin Klips® Four-Terminal Clips
(2) 100 ohm/step SR 1010 with shorting bars and PC 101 parallel and SPC 102 series-parallel compensation networks
(3) 10 ohm SR 1 certified standard resistor
(4) 100 ohm and 1 kilohm SR 1 standard resistors to be calibrated
(5) A black and a white 18 inch plug leads
(6) A data sheet as shown below

DATA SHEET

SR 1	10 ohms	Certified Value	10 ohms_____ppm
SR 1010	100 ohms/step	PARALLEL Calibrated Value (Δ_{AV})	10 ohms_____ppm
SR 1010	100 ohms/step	R_{10}: Series-Parallel Deviation (Δ_D)	100 ohms_____ppm
SR 1010	100 ohms/step	SERIES-PARALLEL Calibration	

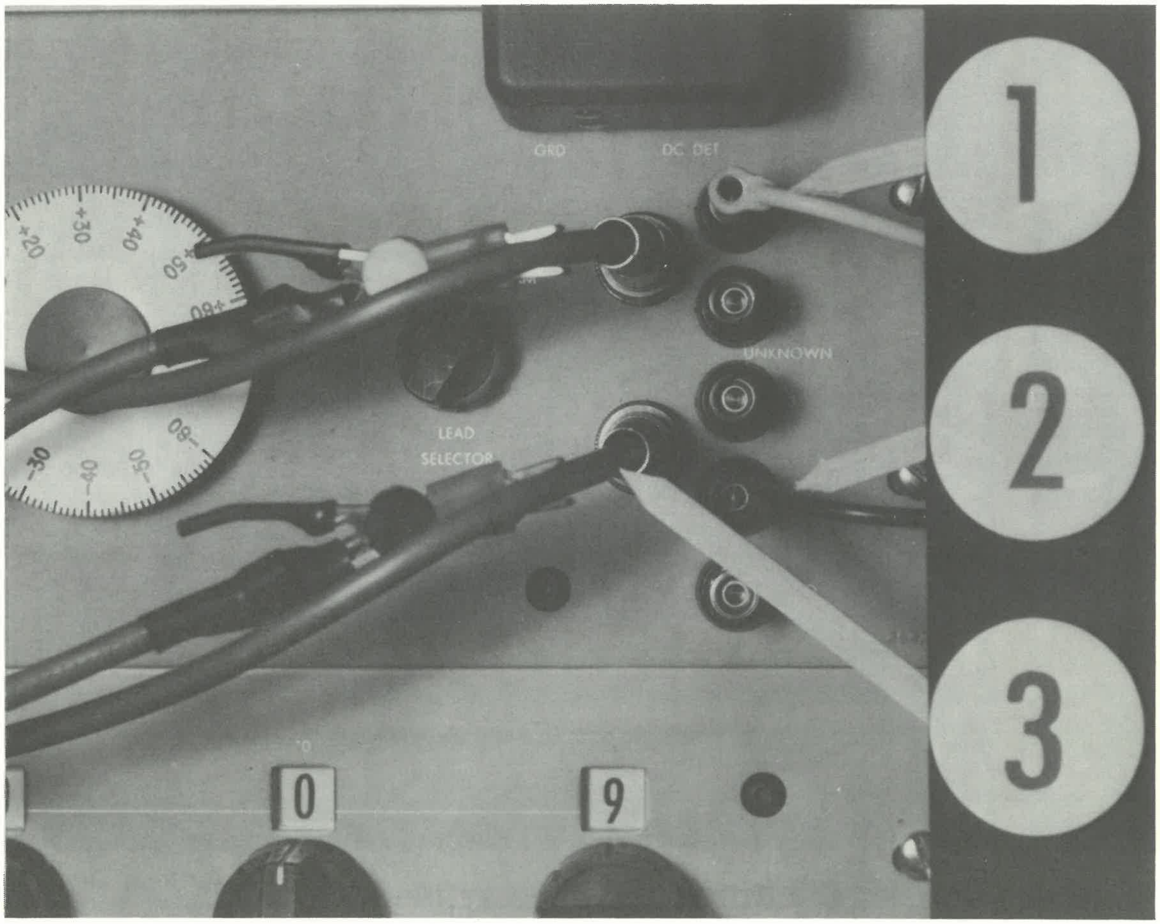
$$\Delta sp\_\_\_\_\_\_ = \left(\Delta_{AV}\_\_\_\_\_\_ + \frac{\Delta_D}{10}\_\_\_\_\_\_\right)$$

SR 1	100 ohms	CALIBRATED VALUE	100 ohms_____ppm
SR 1	1000 ohms	CALIBRATED VALUE	1000 ohms_____ppm



242 GENERATOR-DETECTOR DIAL SETTINGS

(1) GENERATOR POWER, Set to 250 MILLIWATTS
(2) GENERATOR RESISTANCE, Set to 10 Ohms
(3) POLARITY Switch, Set to Minus
(4) GENerator Switch OFF
(5) DETECTOR VARIABLE Control, Turn full clockwise
(6) DETECTOR RANGE Switch, Set to 10 MICROVOLTS
(7) POWER Switch ON

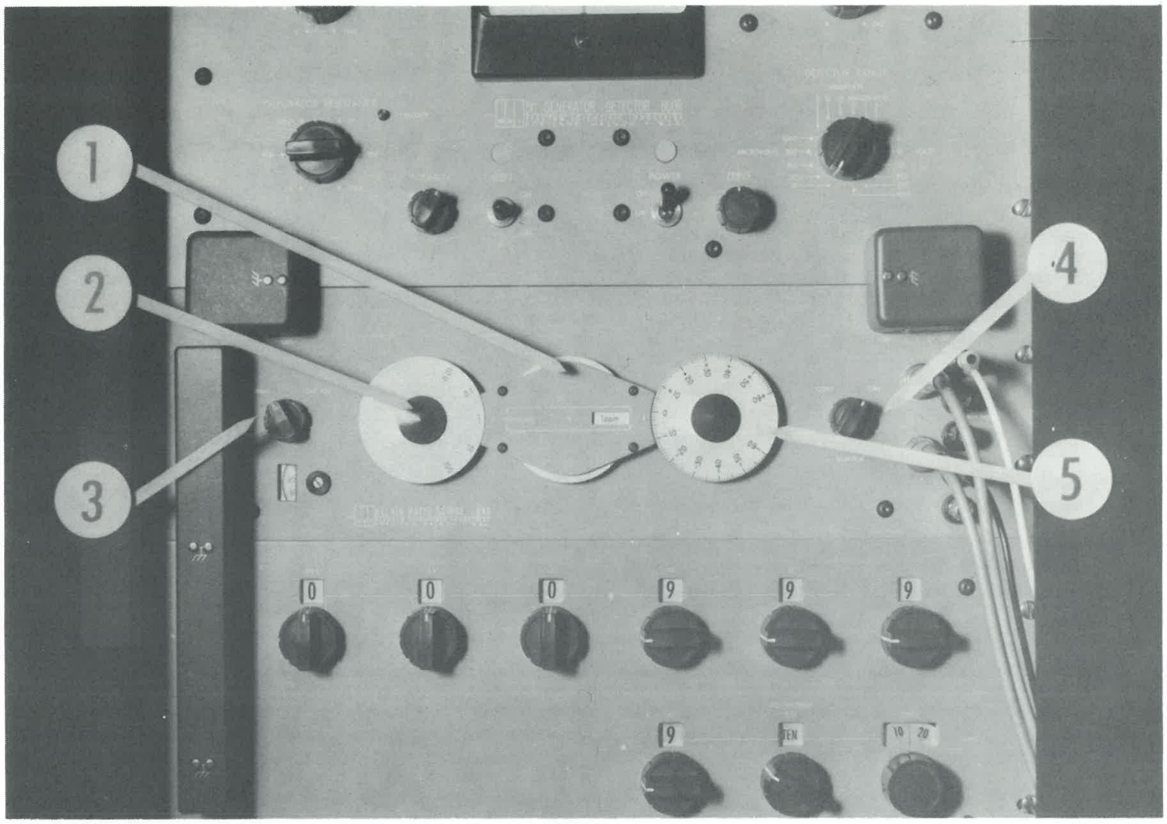


242 LEAD CONNECTIONS

(1) White 18" Plug Lead, Connect one end to 242 Bridge UNKNOWN Terminal 1

(2) Black 18" Plug Lead, Connect one end to Bridge UNKNOWN Terminal 4

(3) The two Kelvin Klip Shielded Coax Leads are already attached to the 242 Bridge just to the left of UNKNOWN Terminals 1 and 4. Examine the clip ends of the leads. Make sure the upper clip has a white center and the lower clip a black center



242 BRIDGE DIAL SETTINGS

(1) Directly in the center of the Bridge is the Deviation Range Dial. Set this dial to 1 ppm. The 1 ppm will appear in the small window on the right side of the dial mask.

(2) To the left of this dial is the Standard Multiplier Dial. Set this dial to 1.

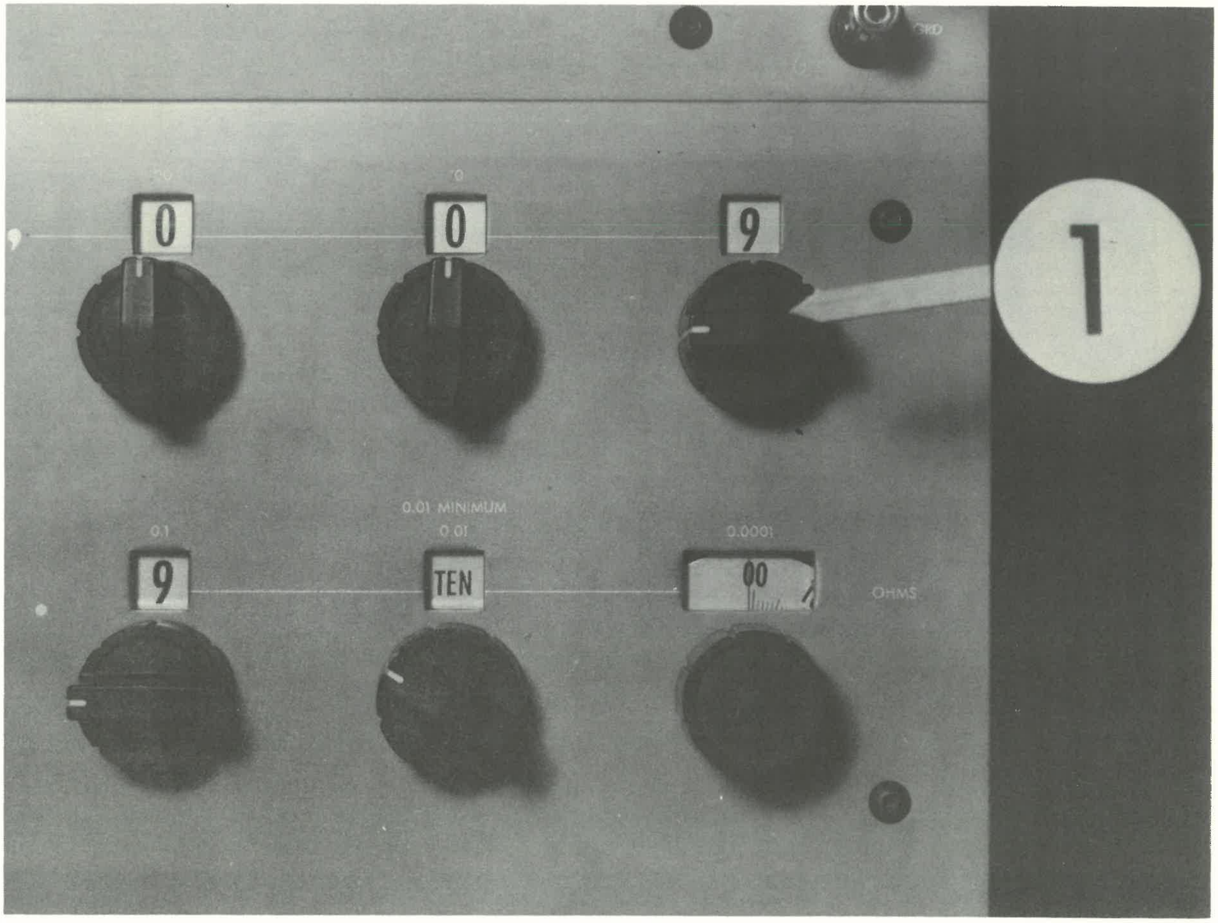
(3) LEAD ADJust Switch, Set to NORMAL

(4) LEAD SELECTOR Switch, Set to TERMinal

(5) Pick up the SR 1, 10 Ohm Standard Resistor and find its certified value. Subtract the nominal value (10 ohms in this case) from the certified value. Divide the result by the nominal value (10) and by one million. This is the certified deviation in ppm. This deviation is plus if the certified value is above the nominal value, minus if it is below. Set the certified deviation on the Bridge Deviation Dial.

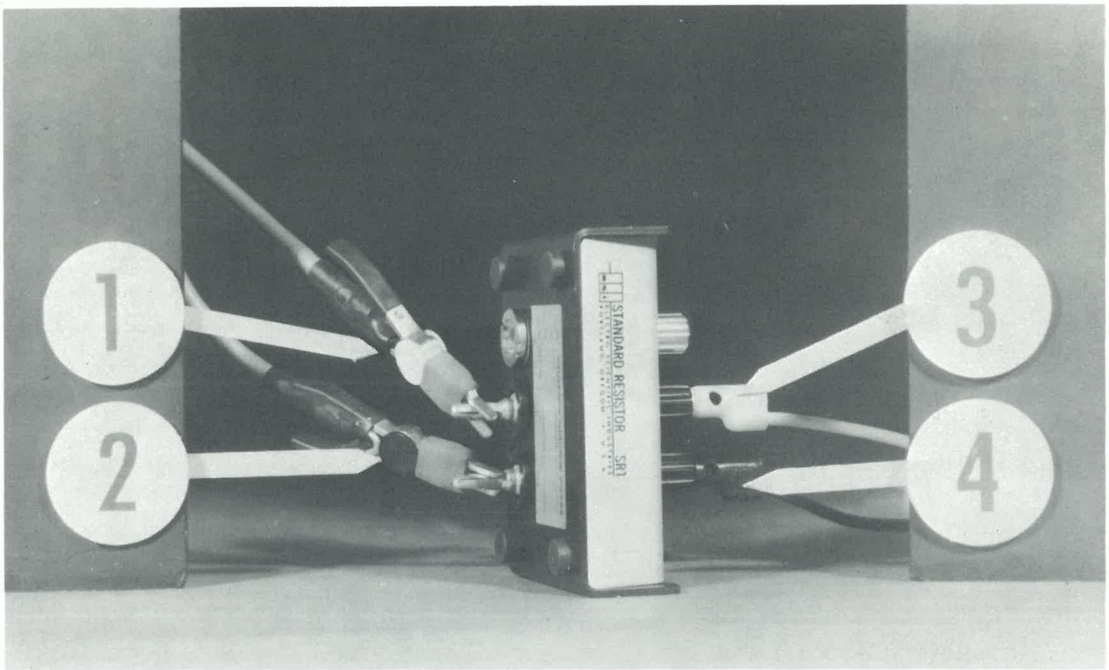
(6) Record the certified deviation on the Data Sheet

SR 1 10 ohms Certified Value 10 ohms_________ppm



242 RESISTANCE STANDARD DIAL SETTING

(1) RESISTANCE STANDARD Dials, Set to 9 .9 TEN 00 for Ten Ohms. Check that all other dials on the RESISTANCE STANDARD are set to 0.



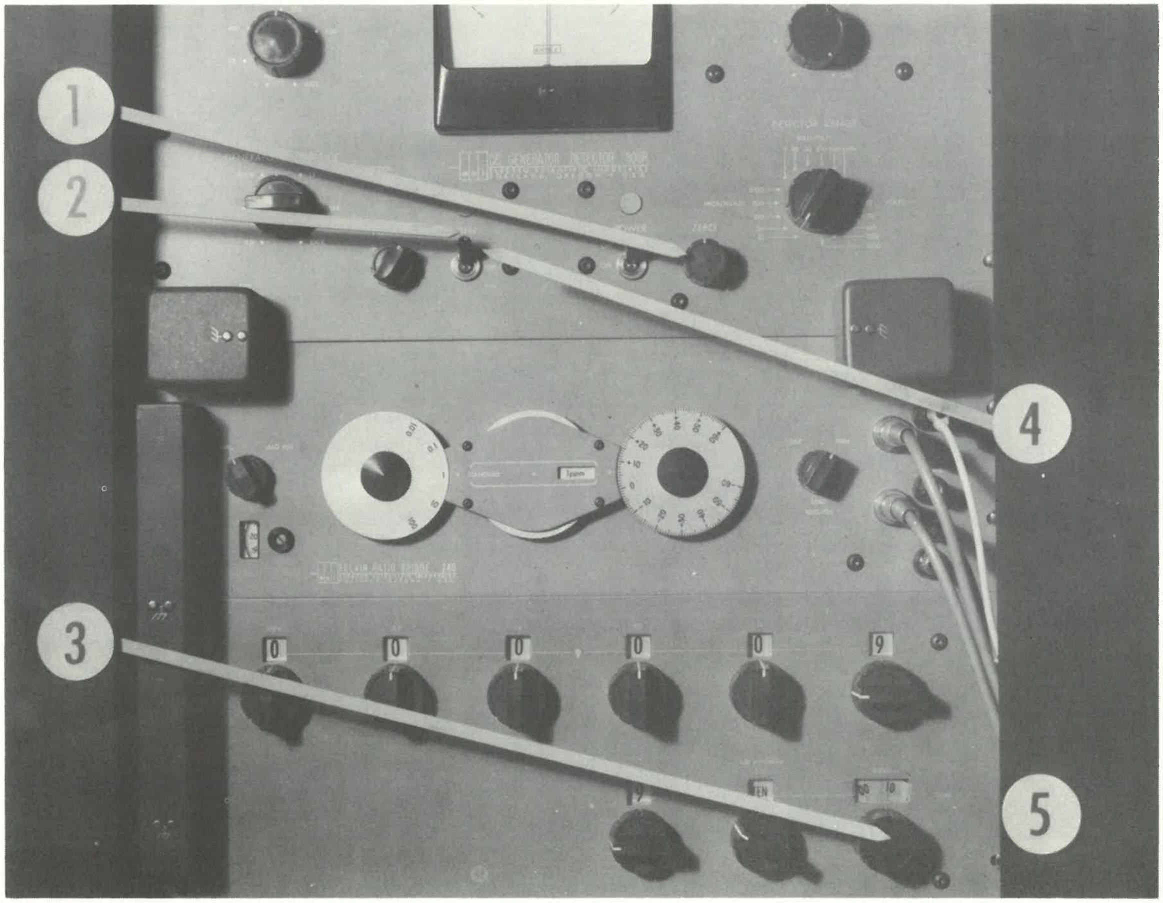
10 OHM STANDARD RESISTOR CONNECTION

(1) Pick up the 10Ω SR 1 and connect the White Kelvin Klip to the banana plug on the bottom of Terminal 1

(2) Connect the Black Kelvin Klip to the banana plug on the bottom of Terminal 2

(3) Connect the White Plug Lead to Terminal 1

(4) Connect the Black Plug Lead to Terminal 2



242 SYSTEM CALIBRATION AT 10 OHMS

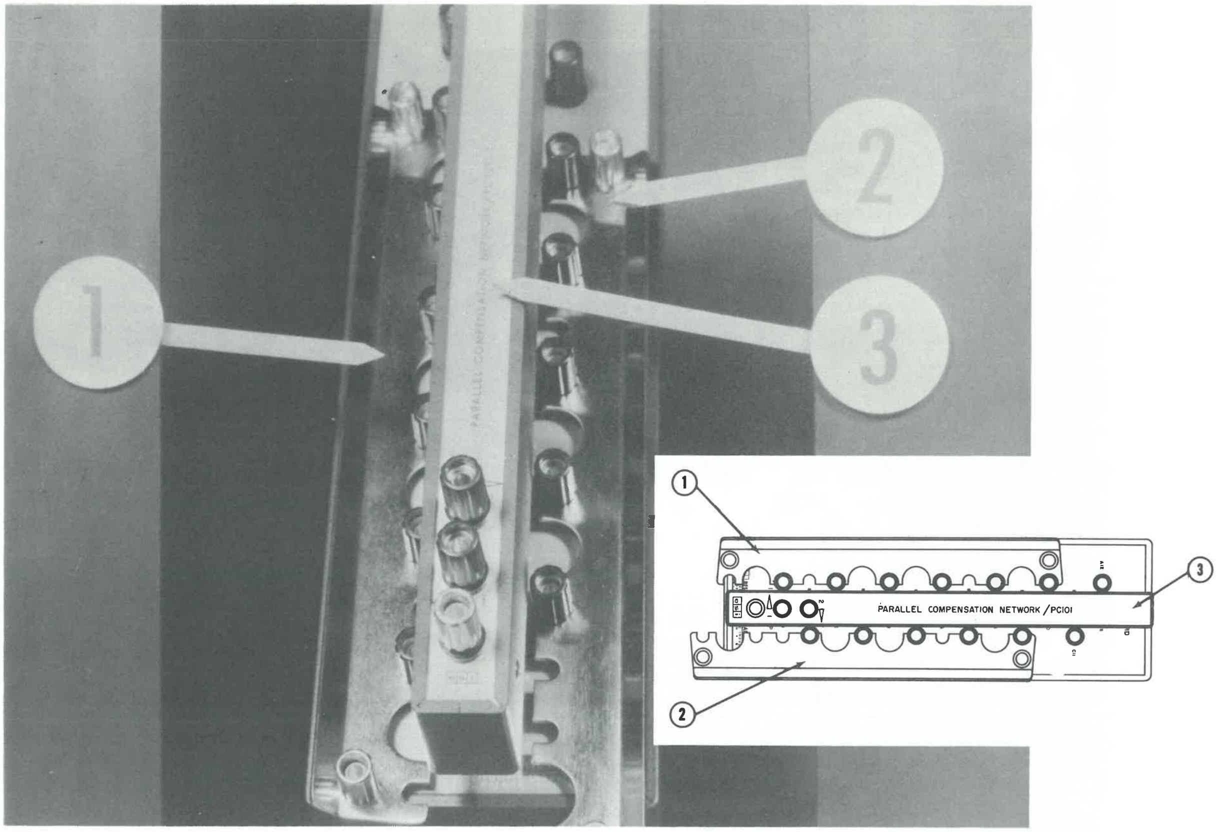
(1) 242 ZERO Control, Adjust for Meter Zero

(2) GENerator Switch, Set to upper ON position

(3) Adjust the RESISTANCE STANDARD starting with the x0.0001 Dial for a Meter Null. (If the Meter Pointer is off scale, change the DETECTOR RANGE to reduce sensitivity. Return to 10 MICROVOLT position for final Null Balance.) The 242 System is now calibrated for 10Ω in terms of the 10 Ohm Standard Resistor.

(4) GENerator Switch OFF

(5) Remove all leads from the SR 1


1
2
3
PARALLEL COMPENSATION NETWORK
①
②
③
PARALLEL COMPENSATION NETWORK /PC101

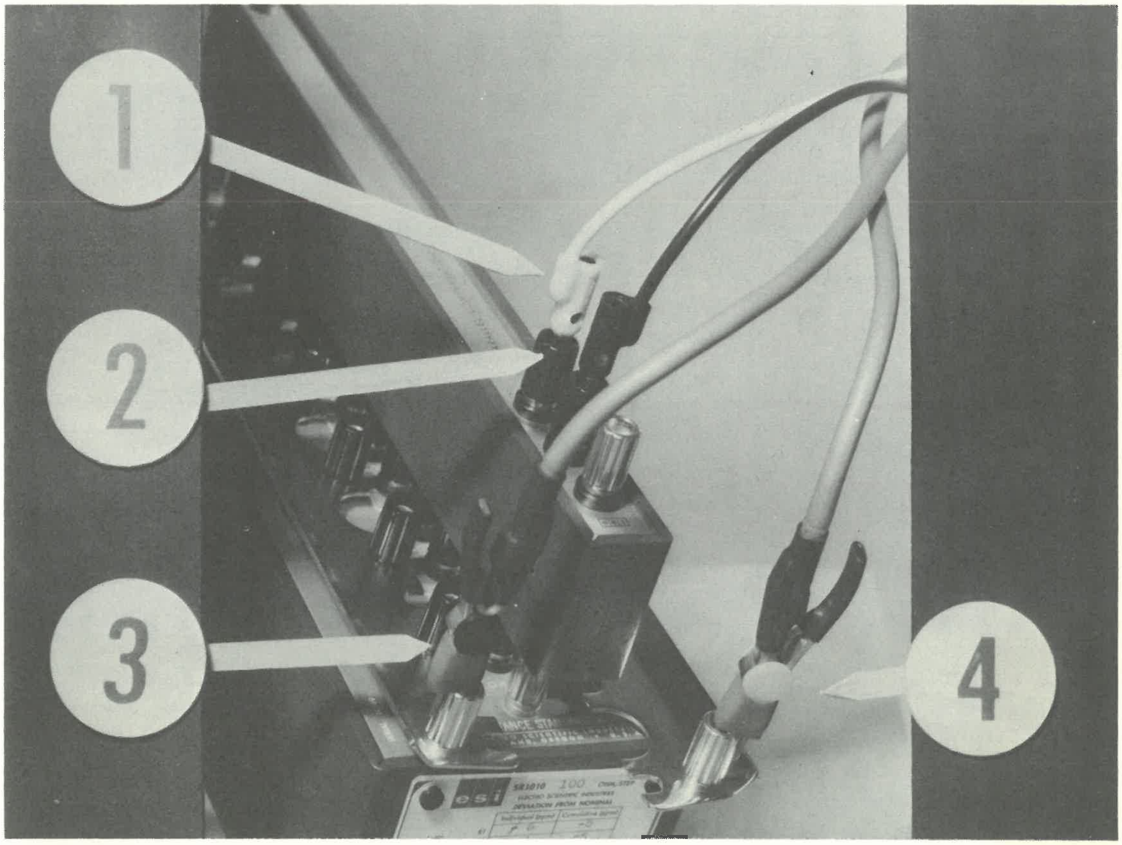
100 OHM/STEP SR 1010 CALIBRATION AT 10 OHMS

Shorting Bar and Network Connections:

(1) Pick up the SR 1010 100Ω/Step box and place it so that the Calibration Card end faces you. Hold a gold-plated Shorting Bar beside the row of binding posts on your left so that its end binding post is opposite A10. Connect the Shorting Bar at A10, A8, A6, A4, A2, and A0. Tighten these binding posts.

(2) Hold the other Shorting Bar on your right so its end binding post is opposite C9. Connect the Shorting Bar at C9, C7, C5, C3, C1. Tighten these binding posts.

(3) Pick up the PC 101 Network. Place the gold GRD Terminal on the Network above the gold GRD Terminal at the Calibration Card end of the SR 1010. Connect the PC 101 Network to the SR 1010 center row of binding posts.



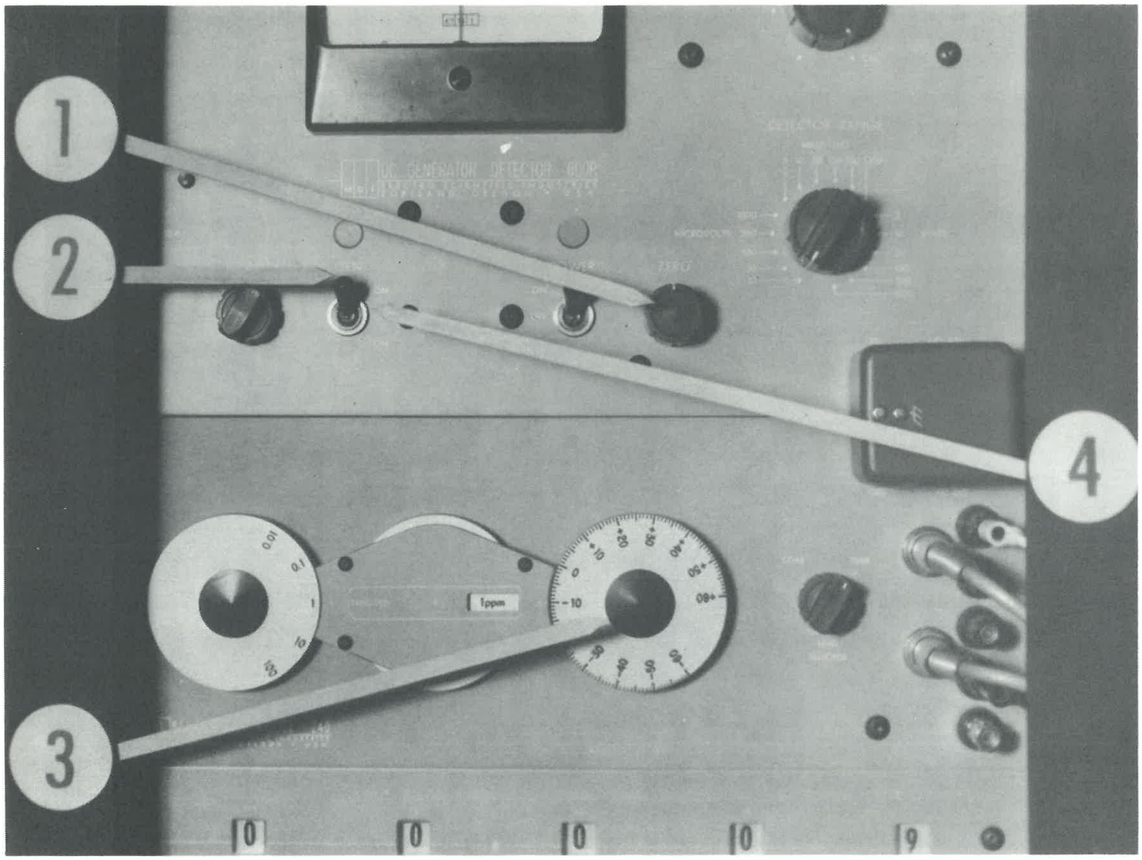
242 LEAD CONNECTIONS TO THE SR 1010

(1) Connect the White Plug Lead to the PC 101 Network Terminal 2

(2) Connect the Black Plug Lead to the PC 101 Network Terminal 1

(3) Connect the Black Kelvin Klip to the left-hand Shorting Bar binding post. Place one jaw inside and one outside of the binding post

(4) Connect the White Kelvin Klip to the right-hand Shorting Bar binding post



SR 1010 DEVIATION MEASUREMENT

(1) 242 ZERO Control, Adjust for Meter Zero

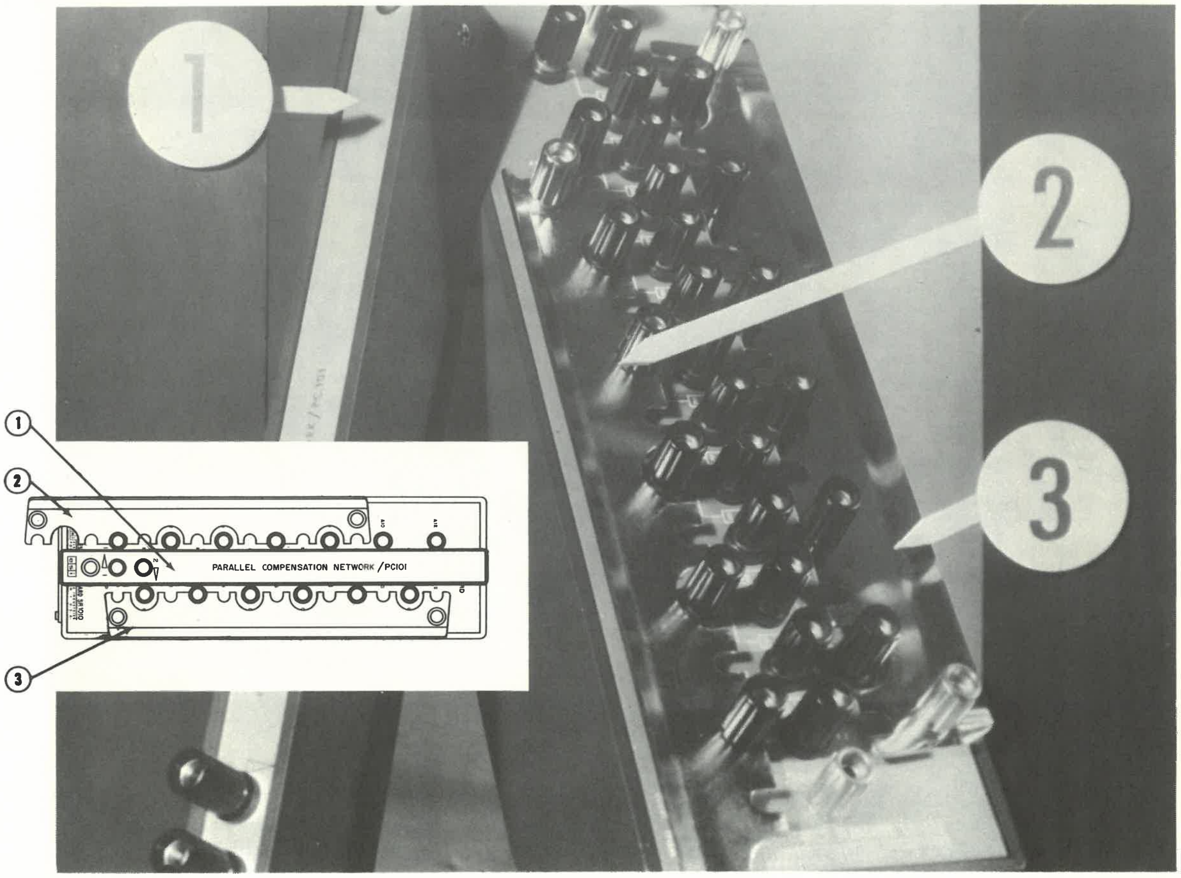
(2) GENerator Switch, Set to upper ON position

(3) Rotate the Bridge Deviation Dial for a Meter Null

(4) GENerator Switch OFF; Record the Deviation Dial reading on the Data Sheet.* This is Δ_{AV}; the deviation of Ten 100 Ohm Resistors in parallel from the calibrated 10 Ohm value of the 242 System.

(5) Remove all leads from the SR 1010 Shorting Bars and Network

*SR 1010 100 Ohms/Step PARALLEL Calibrated Value (Δ_{AV}) 10 ohms____ppm



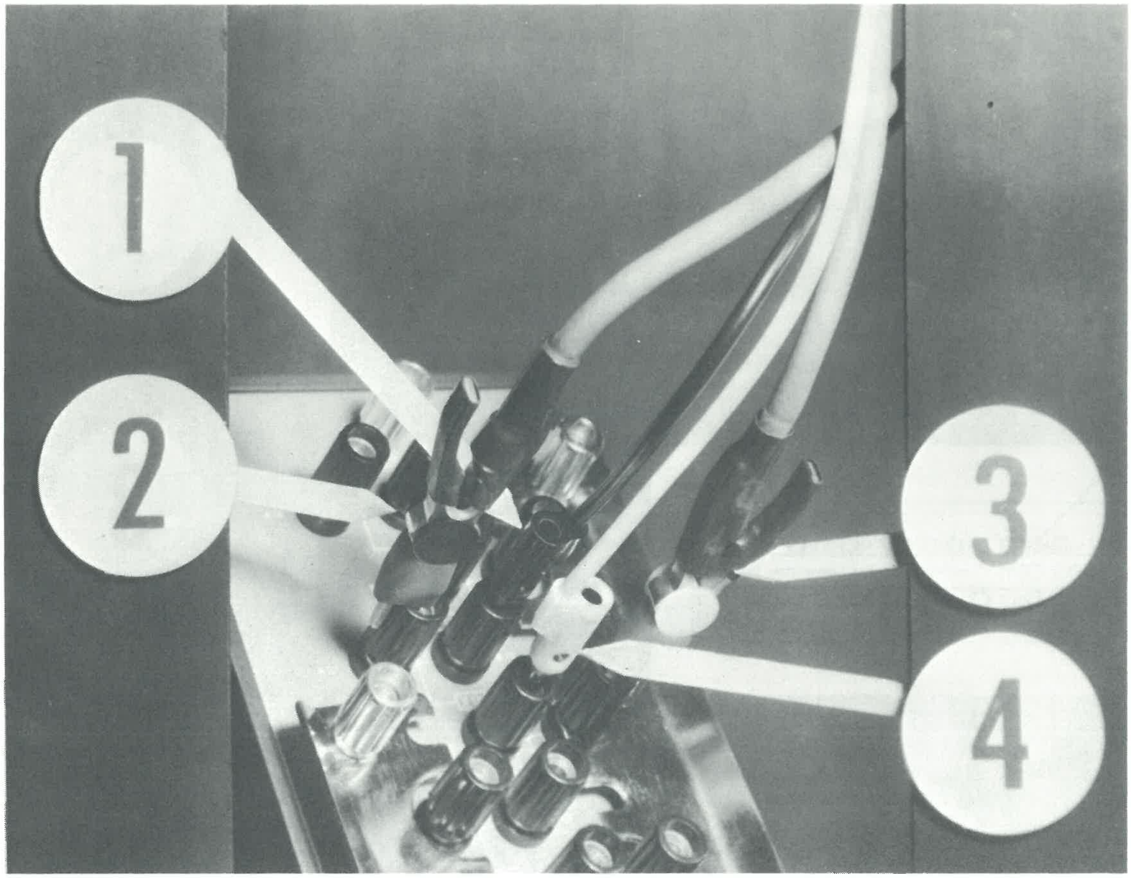
242 CALIBRATION AT 100 OHMS

Shorting Bar Connection:

(1) Remove the PC 101 Network From the SR 1010 by grasping both ends of the Network and pulling straight up to avoid bending the banana plugs.

(2) Loosen the left-hand Shorting Bar. With the end binding post opposite B9, connect it at A0 and A6. Tighten these binding posts.

(3) Loosen the right-hand Shorting Bar. With the end Shorting Bar binding posts held opposite B0 and B12, connect at C3 and C9. Tighten these binding posts.



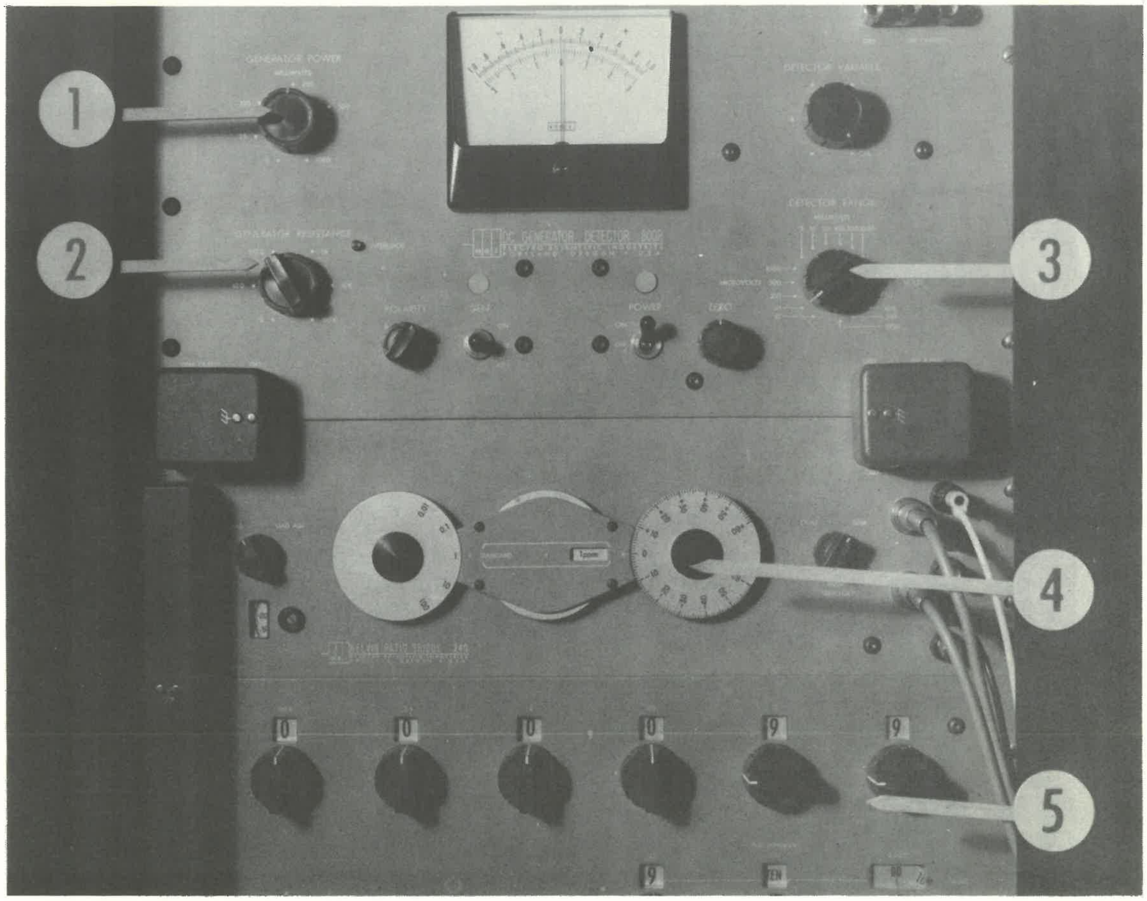
SR 1010 LEAD CONNECTION

(1) Connect the Black Plug Lead to SR 1010 Terminal B-10

(2) Pick up the Black Kelvin Klip. Observe that one jaw is directly connected to the Coax cable. Connect the Black Kelvin Klip to Terminal A10 so that this jaw is in contact with the interior surface of the binding post.

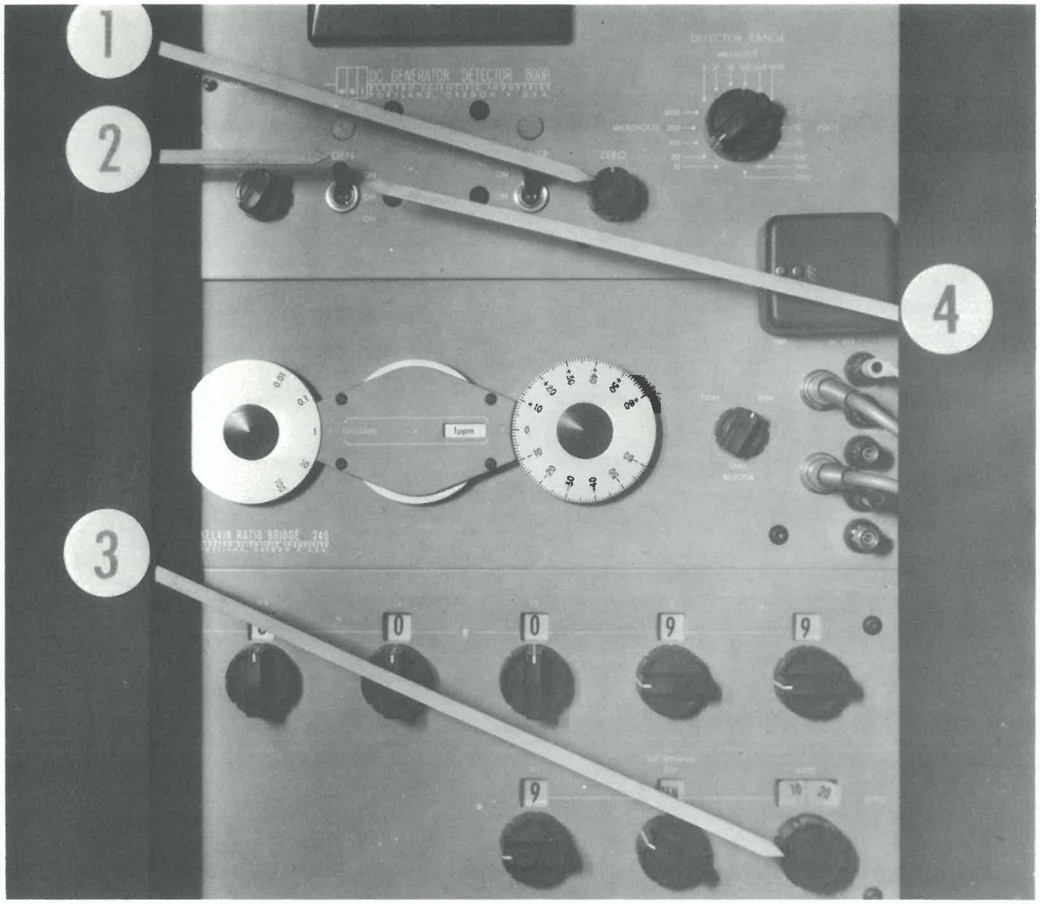
(3) Connect the White Kelvin Klip to Terminal C9 in the same way.

(4) Connect the White Plug Lead to Terminal B9



242 SYSTEM DIAL SETTINGS

(1) GENERATOR POWER, Set to 250 MILLIWATTS
(2) GENERATOR RESISTANCE, Set to 100Ω
(3) DETECTOR RANGE Switch, Set to 30 MICROVOLTS
(4) Bridge Deviation Dial, Set to 0
(5) Resistance Standard x10 Dial, Rotate counter clockwise to 9



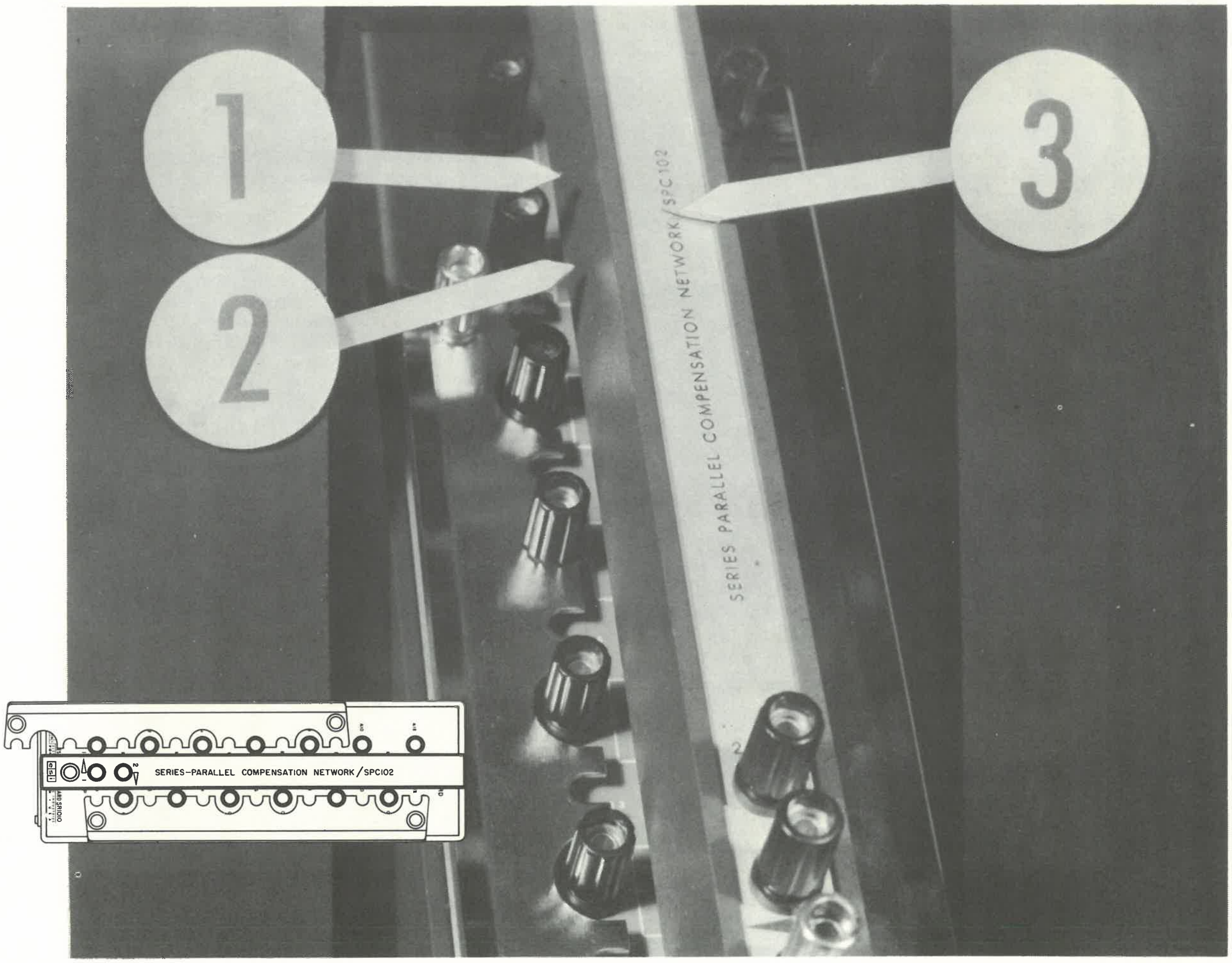
242 MEASUREMENT OF SR 1010 R 10 RESISTOR

(1) 242 ZERO Control, Adjust for Meter Zero

(2) GENerator Switch, Set to upper ON position

(3) Rotate Resistance Standard Dials for Meter Null

(4) GENerator Switch OFF. Check Meter Zero. Repeat if necessary.

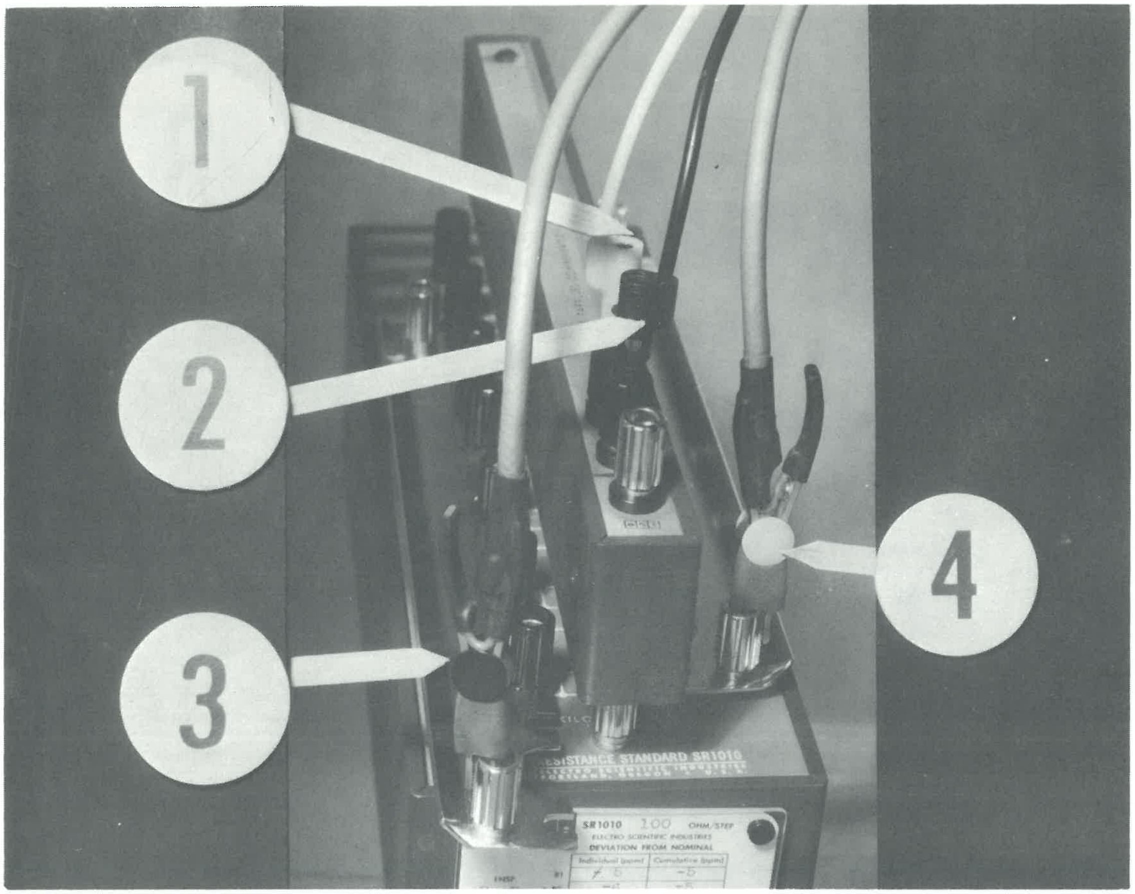

1
2
3
SERIES PARALLEL COMPENSATION NETWORK / SPC 102
SERIES-PARALLEL COMPENSATION NETWORK / SPC102

SR 1010 LEAD AND NETWORK CONNECTIONS

(1) Remove the Black and White Plug Leads from Terminals B-10 and B-9

(2) Remove the Black and White Kelvin Klips from Terminals A-10 and C-9

(3) Pick up the SPC 102 Network. The GRD Terminal on the Network will connect to the GRD Terminal at the Calibration Card end of the SR 1010. Connect SPC 102 Network to center row of terminals on the SR 1010



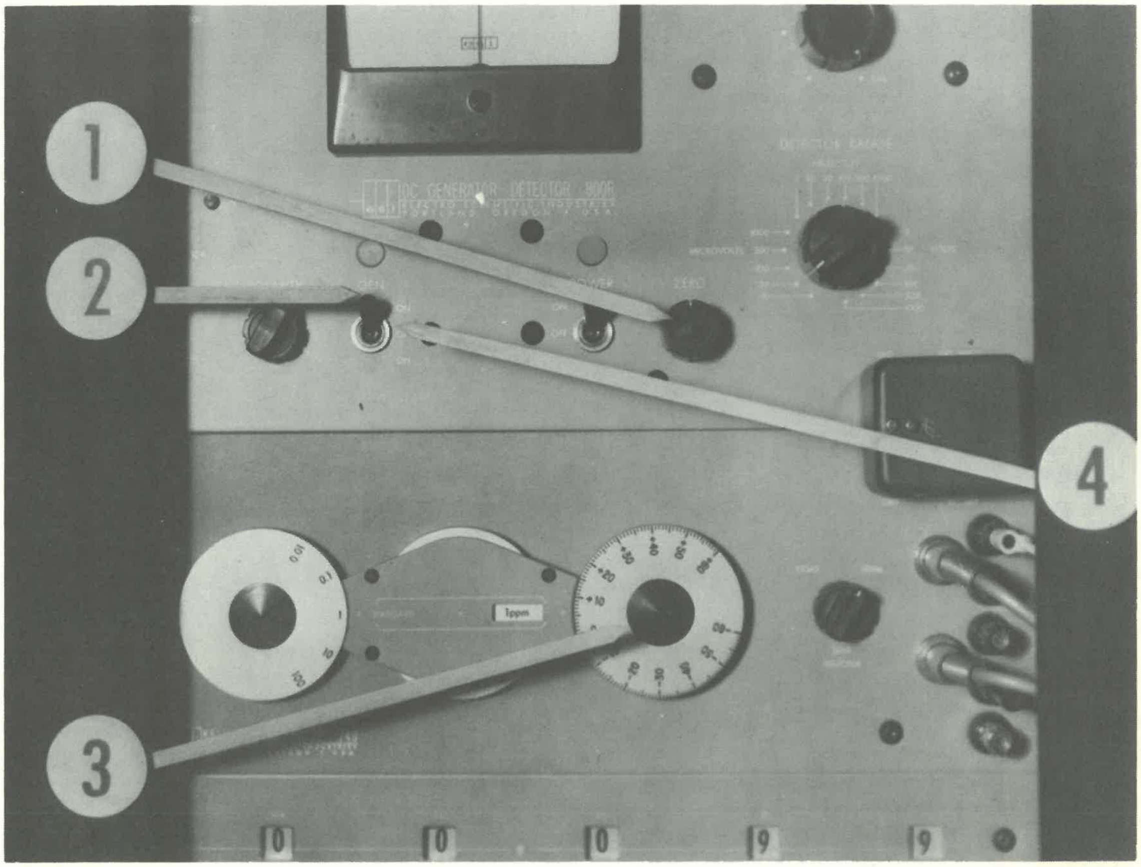
SR 1010 LEAD CONNECTIONS

(1) Connect the White Plug Lead to the SPC 102 Network Terminal 2

(2) Connect the Black Plug Lead to the SPC 102 Network Terminal 1

(3) Connect the Black Kelvin Klip to the left-hand Shorting Bar binding post

(4) Connect the White Kelvin Klip to the right-hand Shorting Bar binding post



SR 1010 SERIES-PARALLEL DEVIATION FROM R 10

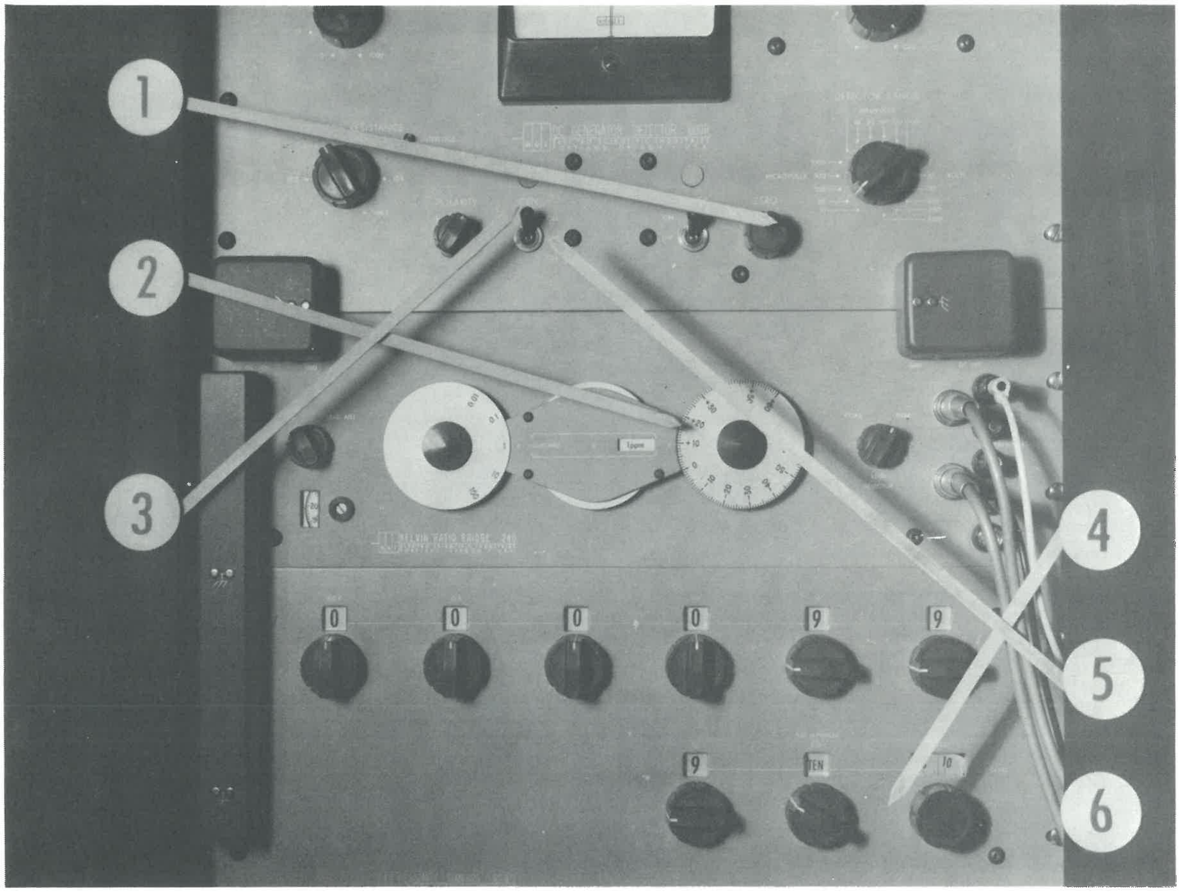
(1) 242 ZERO Control, Adjust for Meter Zero
(2) GENerator Switch, Set to upper ON position
(3) Rotate Bridge Deviation Dial for Meter Null
(4) GENerator Switch OFF

Record the Deviation reading on the Data Sheet* as Δ_D; This is the deviation of the series-parallel combination of the nine 100 Ohm Resistors from R 10.

Calculate Δ_{sp} on the Data Sheet, using the printed equation. Δ_{sp} is the deviation of the series-parallel connection from 10 times the nominal value of the 10 Ohm Standard relative to its Certificate.

*SR 1010 100ohms/step R_{10}: Series-Parallel Deviation (Δ_D) 100 ohms____ppm
SR 1010 100ohms/step SERIES-PARALLEL Calibration

$$\Delta_{sp}\_\_\_\_ = (\Delta_{AV}\_\_\_\_ + \frac{AD}{10}\ \_\_\_\_)$$



242 BRIDGE CALIBRATION AT 100 OHMS

(1) 242 ZERO Control, Adjust for Meter Zero

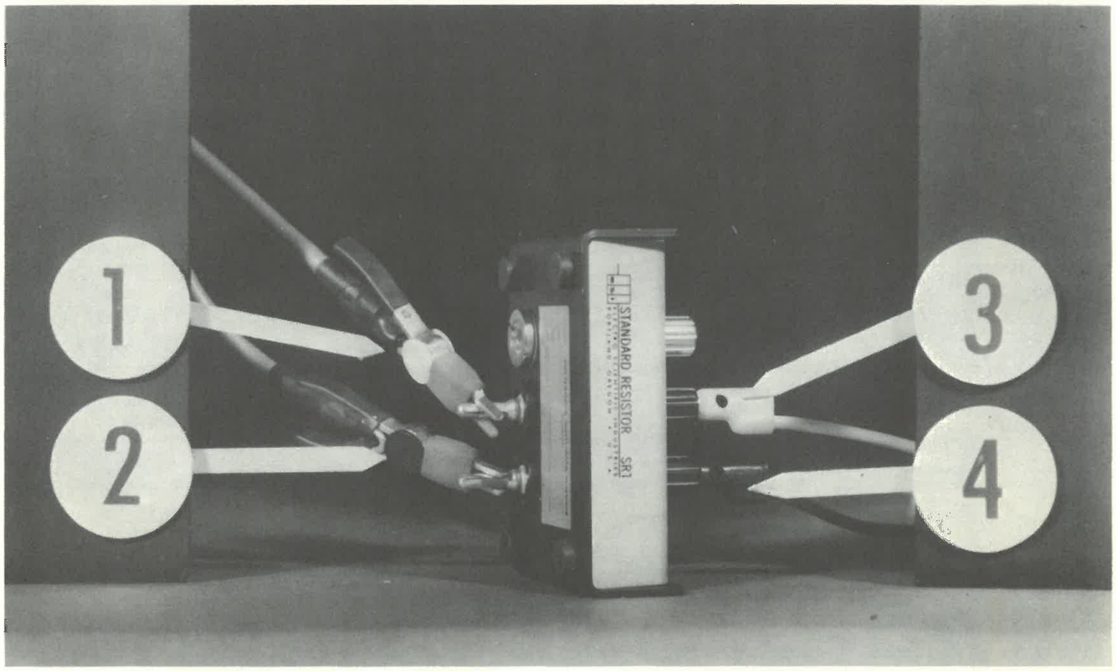
(2) Bridge Deviation Dial, Set to Δ_{sp}

(3) GENerator Switch, Set to upper ON position

(4) Rotate Resistance Standard Dials for Meter Null

(5) GENerator Switch OFF. The 242 Bridge is now calibrated to read 100 Ohms relative to the 10 Ohm Standard Certified Accuracy.

(6) Remove all leads from the SR 1010. Remove the SPC 102 Resistance Network by grasping the ends of the Network and pulling straight up to avoid bending the banana plugs. Remove the Shorting Bars. Finger-tighten all loose binding posts on the SR 1010.



100 OHM SR 1 CALIBRATION

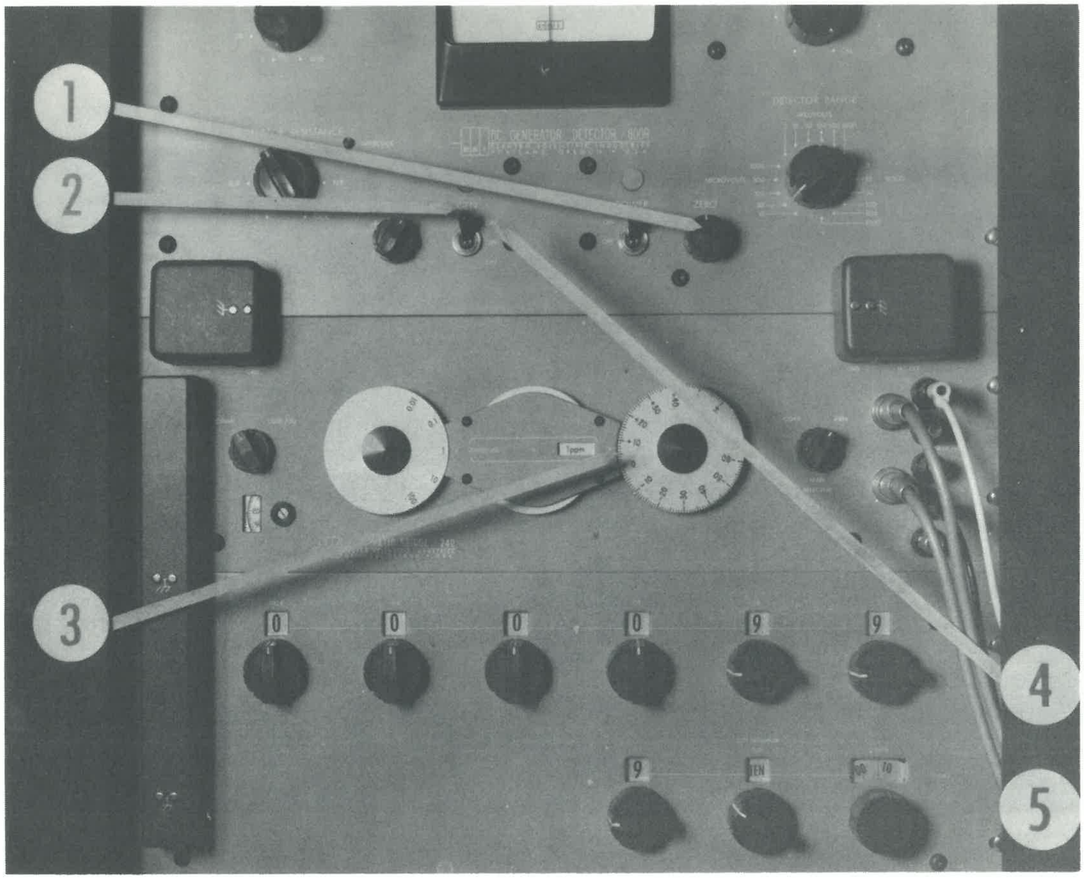
100 Ohm SR 1 Lead Connections:

(1) Pick up the 100Ω SR 1 and connect the White Kelvin Klip to the banana plug on the bottom of Terminal 1

(2) Connect the Black Kelvin Klip to the banana plug on the bottom of Terminal 2

(3) Connect the White Plug Lead to Terminal 1

(4) Connect the Black Plug Lead to Terminal 2



242 CALIBRATION OF 100 OHM SR 1

(1) 242 ZERO Control, Adjust for Meter Zero

(2) GENerator Switch, Set to upper ON position

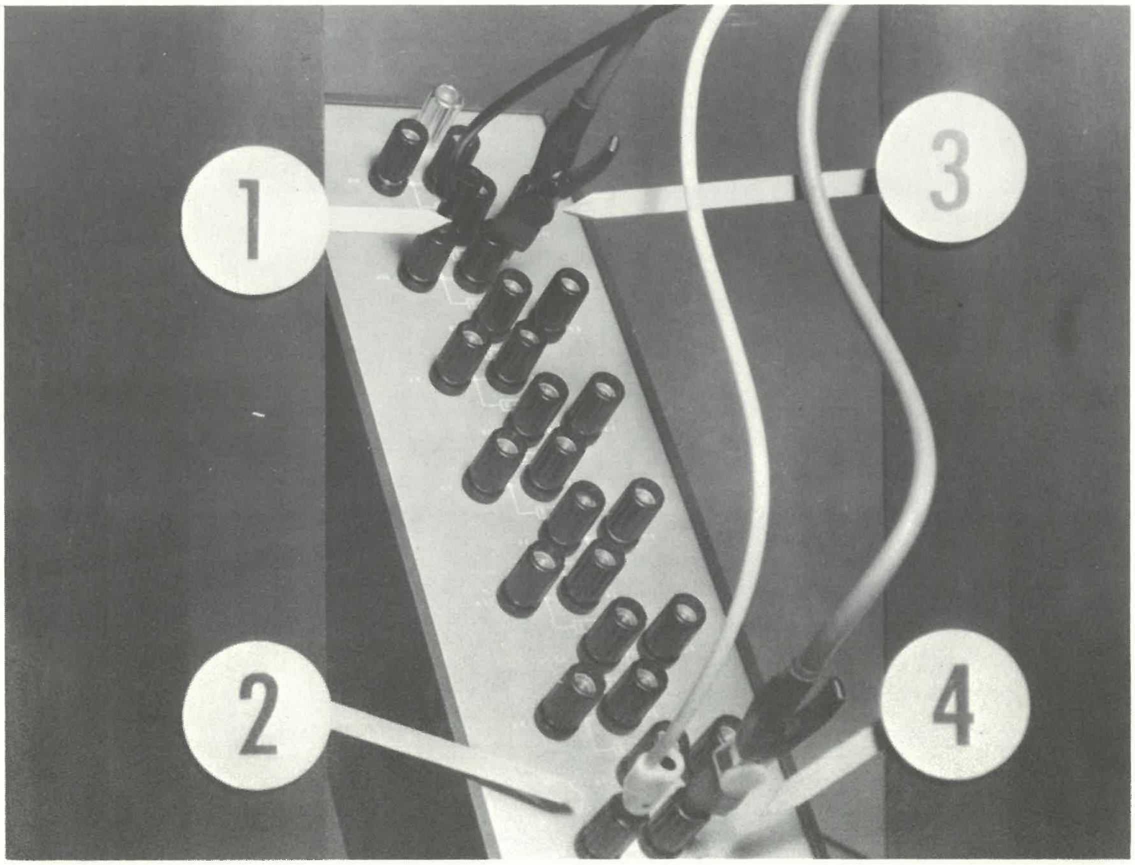
(3) Rotate Bridge Deviation Dial for Meter Null

(4) GENerator Switch OFF

Record the Deviation Dial reading on the Data Sheet.* This is the deviation of the 100 Ohm SR 1 Standard Resistor from its nominal value relative to the Certified Deviation of the 10 Ohm Standard within the accuracy of the transfer measurement.

(5) Remove all leads from the 100 Ohm SR 1

*SR 1 100 ohms CALIBRATED VALUE 100 ohms____ppm



242 BRIDGE CALIBRATION AT 1 KILOHM

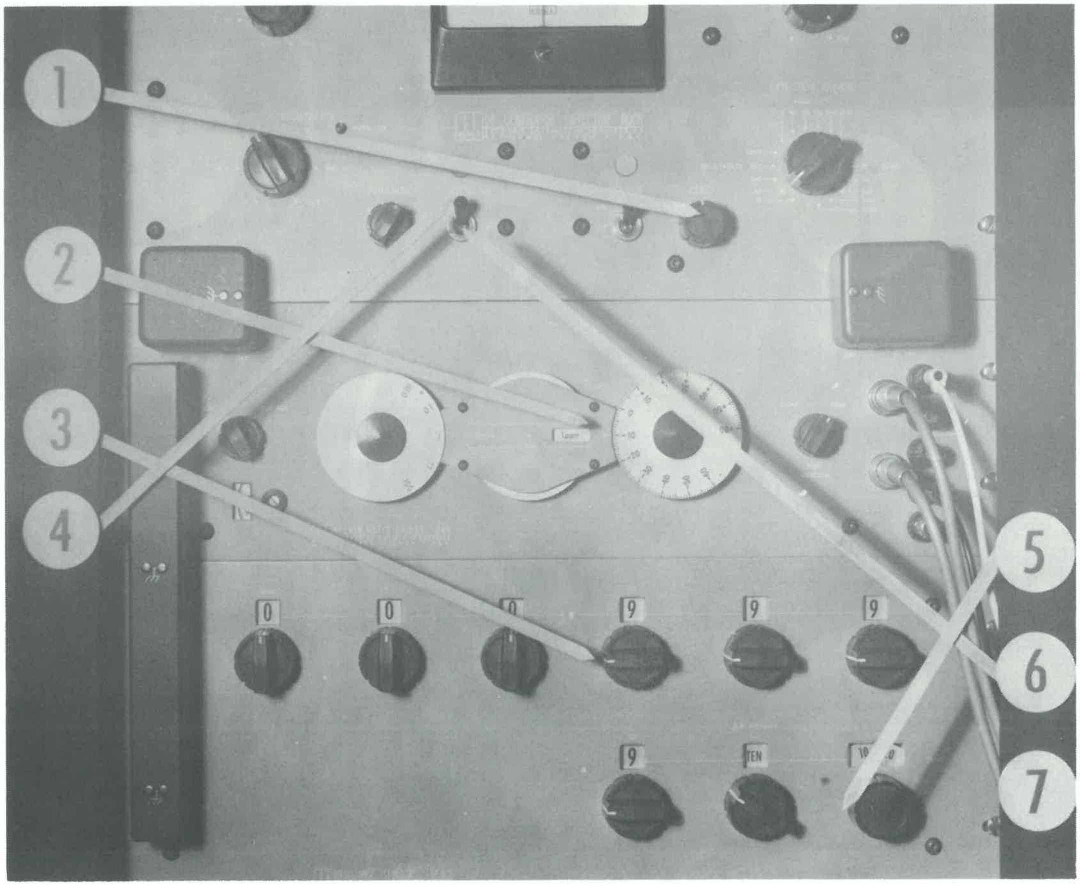
SR 1010 Lead Connections:

(1) Connect the Black Plug Lead to Terminal A-10

(2) Connect the White Plug Lead to Terminal A-0

(3) Connect the Black Kelvin Klip to Terminal B-10

(4) Connect the White Kelvin Klip to Terminal B-0. Remember, Kelvin Klips are connected to the SR 1010 Terminal with the jaw, to which the Coax cable is attached, in contact with the interior surface of the binding post.



242 BRIDGE CALIBRATION AT 1 KILOHM

(1) 242 ZERO Control, Adjust for Meter Zero

(2) Bridge Deviation Dial, Set to Δ_{AV}

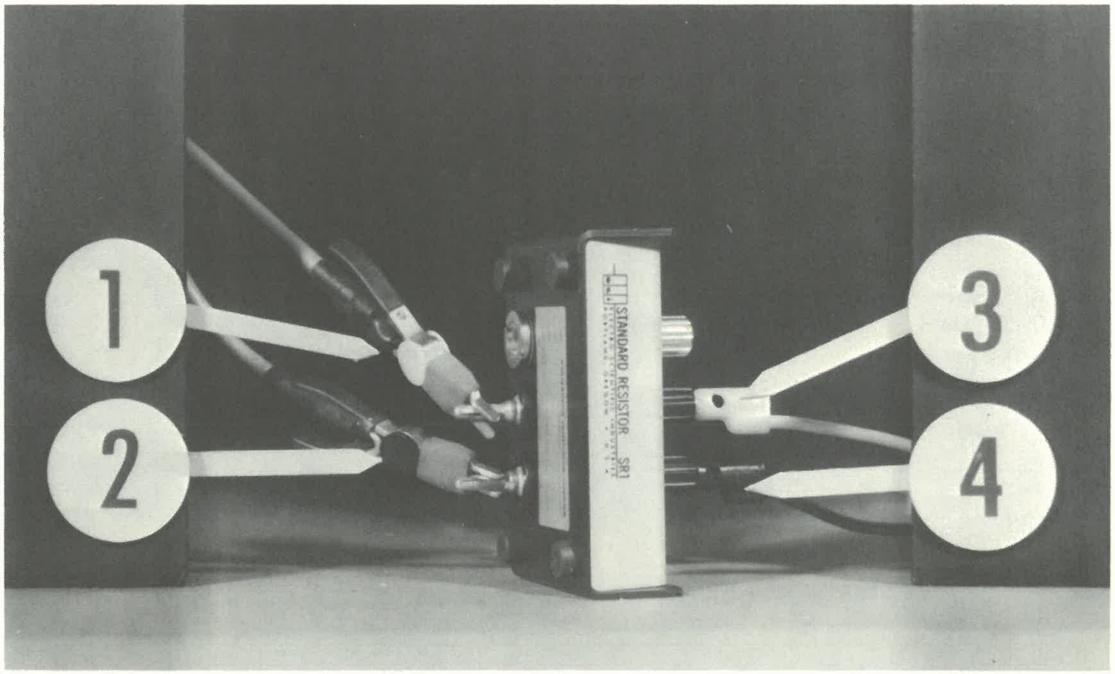
(3) Resistance Standard x100 Dial, Rotate counter-clockwise to 9

(4) GENerator Switch, Set to upper ON position

(5) Resistance Standard Dials, Rotate for Meter Null

(6) GENerator Switch OFF. The 242 Bridge is now calibrated to measure a 1 Kilohm resistance.

(7) Remove all leads from the SR 1010



CALIBRATION OF 1 KILOHM SR 1 STANDARD RESISTOR

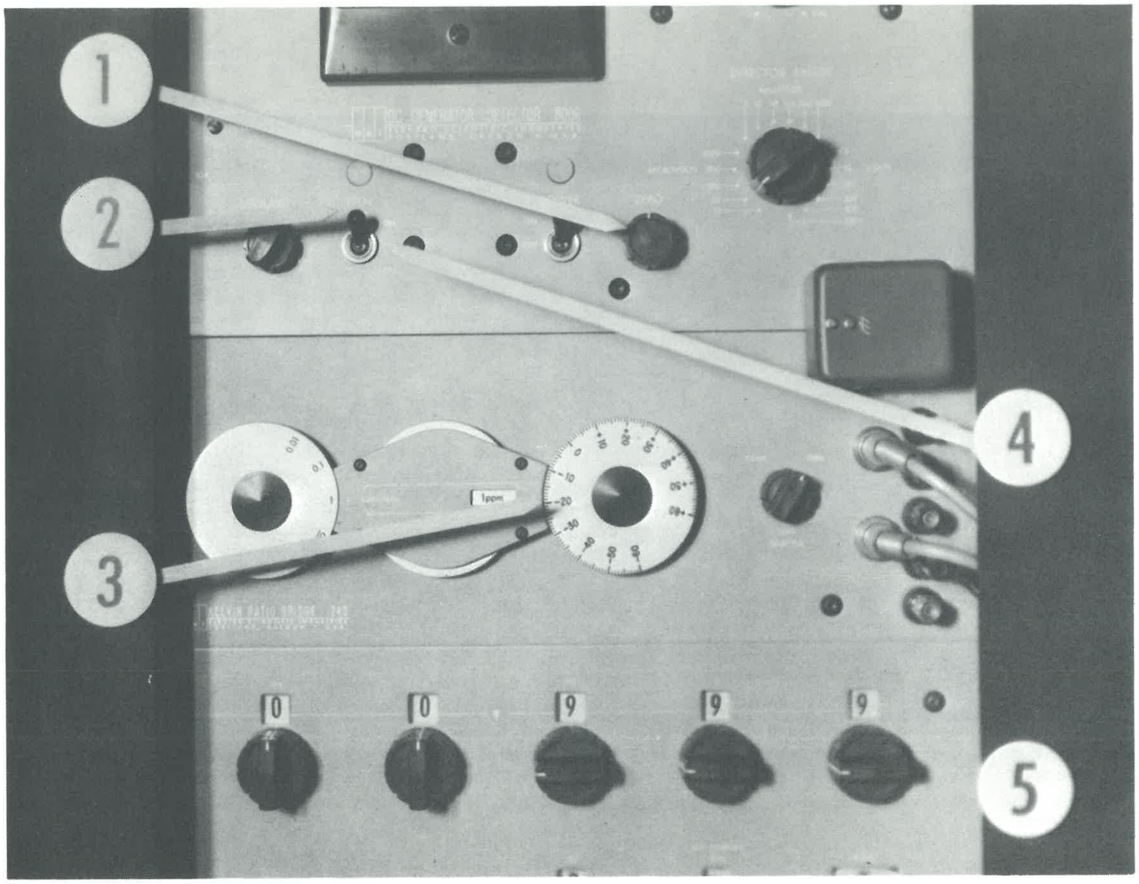
1 Kilohm SR 1 Lead Connections:

(1) Pick up the 1 Kilohm SR 1 and connect the White Kelvin Klip to the banana plug on the bottom of Terminal 1

(2) Connect the Black Kelvin Klip to the banana plug on the bottom of Terminal 2

(3) Connect the White Plug Lead to Terminal 1

(4) Connect the Black Plug Lead to Terminal 2



242 CALIBRATION OF 1 KILOHM SR 1

(1) 242 ZERO Control, Adjust for Meter Zero

(2) GENerator Switch, Set to upper ON position

(3) Bridge Deviation Dial, Rotate for Meter Null

(4) GENerator Switch OFF

Record* the Deviation Dial reading. This is the deviation of the 1 Kilohm SR 1 Standard Resistor from its nominal value relative to the Certified Deviation of the 10 Ohm Standard within the accuracy of the transfer measurement.

(5) Remove all leads from the 1 Kilohm SR 1

*SR 1 1000 ohms CALIBRATED VALUE 1000 ohms____ppm

RESISTANCE TRANSFER

DATA SHEET

SR-1	10 ohms	Certified Value	10 ohms_____ppm
SR-1010	100 ohms/step	PARALLEL Calibrated Value ($\triangle_{AV}$)	10 ohms_____ppm
SR-1010	100 ohms/step	R_{10}: Series Parallel Deviation ($\triangle_D$)	100 ohms_____ppm
SR-1010	100 ohms/step	SERIES PARALLEL Calibration	

$$\triangle sp\_\_\_\_\_\_ = \left(\triangle_{AV}\_\_\_\_\_\_ + \frac{\triangle_D}{10}\_\_\_\_\_\_\right)$$

SR-1	100 ohms	CALIBRATED VALUE	100 ohms_____ppm
SR-1	1000 ohms	CALIBRATED VALUE	1000 ohms_____ppm